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UNITED STATES DEPARTMENT OF AGRICULTURE

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THE ROLE OF FOREST VEGETATION IN FLOOD CONTROL PROBLEMS IN LOS ANGELES COUNTY

Statement by
California Forest & Range Experiment Station
and Forest Supervisor, Angeles National Forest
U. S. Forest Service

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Submitted to Major Theodore Wyman, U. S. Engineers
in connection with the hearing on a flood
control plan for Los Angeles County
held in Los Angeles, March 31, 1936

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Approximately 40% of the drainage basins of the Los Angeles and San Gabriel Rivers is a mountainous area, largely within the Angeles National Forest in the San Gabriel Mountain Range. In developing a comprehensive flood control plan for these two rivers it seems essential to consider how the mountainous part of their drainage basins influences run-off and how the vegetation thereon can be managed to contribute to the prevention or control of floods.

The purpose of this paper is to explain the influence of forest cover of the mountain watersheds in Los Angeles County on:

1. Floods
2. Erosion
3. Water Conservation

Evidence regarding the effect of forest cover upon the above three items is of two broad types, namely:

A. Results of heavy storms on comparable denuded and forest-covered watersheds.

B. Results of experiments in field and laboratory.

Information obtained by careful observation of floods and their causes may have greater immediate value than detailed experimental data for purposes of practical application in formulating a flood control plan. However, the data available from controlled experiments, although limited in quantity, has high value in corroborating the extensive observations and in explaining the causes of flood phenomena.

Forest Cover. Forest Cover in the San Gabriel Mountains consists of three broad types:

(a) Chaparral - 85%. This complex but broadly uniform vegetation is a dwarf forest of shrubs and small trees averaging from 6 to 10 feet in height, and ranging in species from desert sage to scrub oak. This xeric vegetation is well adapted to the semi-arid climate of southern California and is generally regarded as the climax or ultimate vegetation which can survive in that region so long as present climatic conditions continue.

(b) Coniferous forest - 10%. A mixed forest of pine, fir and cedar interspersed with black oak occurs in the higher elevations from approximately 5000 feet upwards. The heaviest precipitation, including considerable snowfall, occurs in this forest which consequently serves as the source of most of the perennial streamflow in the San Gabriel Mountains. The conifer forest has also a high value for recreational purposes. Because of the lower temperatures, greater rainfall and the very nature of the forest itself, this type is less subject to disastrous fires, and fires in it are controlled more easily than in the chaparral forest on the lower slopes.

(c) Canyon bottom woodland - 5%. This type is composed of the narrow groves of sycamore, alder, maple, laurel and other mesophytic species which occur only in the canyon bottoms and for a short distance along the washes beyond the canyon mouths. It has high recreational value in offering picnic grounds, camping grounds and summer home sites to residents of the metropolitan area. From the standpoint of flood control and water conservation, this vegetation has both good and bad qualities: under ordinary conditions during freshet run-off resulting from winter and spring rains, the streamside trees tend to prevent excessive cutting of the canyon bottom soil; during major floods from a burned watershed the canyon trees are broken by boulder flows and the broken logs add to the debris burden of the flood. Regarding water conservation the canyon bottom trees actually consume large quantities of water for their own growth but in return they shade the stream itself and greatly reduce midsummer evaporation; the relation between these two processes has not yet been quantitatively determined.

From the standpoint of flood control the chaparral is far and away the most important vegetation in southern California. It not only occupies 85% of the forest area but it grows on the steep slopes under the most adverse conditions; it is most susceptible to fire of all the types, and when fires once start in it they are most difficult to control. After burning, the chaparral usually recovers with great rapidity both by seed and by sprouting from the burned stumps, providing moderate rainfall occurs. If growing conditions are severe, due either to heavy erosion of top soil by prolonged

intensive rainfall, or to lack of precipitation, this revegetation may be delayed several years. Granting that a cover of vegetation in the watersheds is desirable and in the light of our present knowledge, the native chaparral cannot be excelled by any vegetation within the power of man to develop over large areas on the San Gabriel mountain slopes.

Effect of vegetation on floods. Chaparral cover reduces floods by retarding run-off of rainfall and increasing infiltration of water into soil and underlying rock. The assumption is erroneous that a forest ceases to retard run-off when its ground litter is saturated. Water which enters the soil during heavy storms escapes in two chief ways, not counting for the moment, transpiration and evaporation losses. One part, by shallow seepage and prompt issuance drains into streams in a comparatively short time, a matter of hours rather than days. This quick seepage combines with surface run-off to form the normal rapid rise of stormflow in streams. Another part is delayed by deeper percolation into the underlying rock and its escape is a matter of weeks or even months, depending on the storage capacity of the rock structure. This delayed water serves to reduce stormflow stages and to prolong streamflow after the end of the storm or of rainy season.

In the basins of the Los Angeles and San Gabriel rivers the extreme steepness of the mountains makes for normally rapid run-off, but this is compensated by both the rock structure and the type of vegetation growing above it. The rocks composing the San Gabriel Mountains are for the most part either granitoid or metamorphic in origin and are in a highly shattered condition due to both faulting

and folding. In this rock structure the possibilities for percolation and consequent delay of run-off are almost unlimited when infiltration at the surface is assured by an adequate vegetative cover over porous soil. Precisely these conditions obtain throughout the greater part of the chaparral belt of the San Gabriel Mountains, and thus the capacities of well covered watersheds in this region to receive heavy precipitation without producing disastrous floods are well beyond the volume of most storms occurring in the region.[1/] In consequence of these conditions, major floods are to be expected from well forested watersheds only at those rare times when exceptional storms of prolonged high intensity occur. Records to date indicate that this may be once in 20 to 50 years. Even at such times a good chaparral cover continues to ameliorate conditions by reducing erosion and thus reducing the amount of mineral debris in the run-off. In floods from such areas it is observed that the greater part of the debris comprises dead wood and other organic material which has accumulated in the canyons.

The Montrose Flood. The storm which produced this flood brought an average total of 12 inches of rainfall to the south front of the San Gabriel Mountains over an area roughly 50 miles east-west and 20 miles north-south. Within this area a 5000-acre tract on the south slope of Mt. Lukens had been denuded by fire in the preceding November (1933), approximately one month previous to the storm.

1/ Quantitative effect of chaparral cover in reducing run-off is shown in Table 4, page 10 of the attached mimeographed report of March 14, 1935 "Run-off and Erosion Experiments in Mountain Areas". The quantitative effect of forest litter in reducing run-off and increasing percolation is shown in Table 5, page 14 of the same report.

The burned area was drained by 17 small canyons ranging in size from .2 to 1.5 square miles and all emptying on a sloping valley flood composed of age-old alluvial deposits. The valley floor was occupied by a number of residential communities containing a population of several thousand persons.

The so-called New Years' storm began at noon on December 30 and at midnight, December 31, a series of destructive floods of the torrential mud-and boulder type swept down from the burned area and through the communities of Montrose, La Crescenta and La Canada, causing the death of 30 persons, destroying over 200 homes and rendering nearly 300 others uninhabitable, clogging highways and drainage structures, and amassing a total damage of approximately $5,000,000.

The amount of debris washed down by erosion of the burned slopes and gouged from the canyon bottoms, as determined by catchment in two debris basins and by surveys of deposits in streets and fields of the valley floor, indicated an erosion rate of approximately 100,000 cubic yards per square mile.

Calculation of run-off rates was rendered difficult on account of the enormous debris burden carried by the streams. Conservative estimates place the peak flows well over 500 cubic feet per second per square mile, of water alone, and to this figure most engineers are inclined to add an equal volume of debris.

Comparison with adjacent unburned watershed. In contrast to this flood from the denuded watersheds of Mt. Lukens, the records of the well-forested Arroyo Seco watersheds, only two miles distant, showed the following:

Rainfall: 12 to 19 inches, a greater total for the storm than the burned area received.

Run-off Peak: 58 cubic feet per second per square mile.

Erosion: Negligible.

Damage: Negligible from the stream but some damage caused by erosion from a newly constructed highway within the watershed.

The low run-off rate from the Arroyo Seco in itself reflects the regulating influence of the dense chaparral cover which clothed the entire watershed. Forest officers within the canyon and members of the Pasadena Water Department, which maintains an intake in the Arroyo Seco, stated that the small amount of eroded material transported by the stream in this canyon came almost entirely from the sloughing of unstabilized road slopes.

Comparison of the results of this storm insofar as its run-off was affected by the burned Mt. Lukens and the unburned Arroyo Seco watersheds, shows that the chaparral forest cover in the Arroyo Seco reduced the run-off at least nine-fold and reduced erosion to an extent so great as to be incalculable. The contrast in behavior of streams from forested and from burned watersheds is shown photographically in Plate I.

If one thought to set a value upon the chaparral cover on the basis of the Montrose flood alone, in which 5,000 denuded acres caused $5,000,000 worth of damage, the flood-prevention value would be $1,000 per acre. This figure cannot be taken as a fixed general value, it is offered here merely as indicative of the high value of forest cover in relation to densely populated areas. On the strength of the

behavior of the Arroyo Seco and many other similarly chaparral-covered drainage areas within the storm tract, it is entirely reasonable to assume that if the Mt. Lukens area had not been burned but had met the storm with its former excellent cover of chaparral (unburned since 1878), there would have been no Montrose flood and no serious damage from the clear run-off which would have resulted.

Experimental Evidence

Effect of vegetation on erosion and water conservation. That the chaparral cover on mountain sides reduces erosion and excessive soil movement is a self-evident fact. The effect of this protective action of the chaparral, however, upon water conservation requires emphasis.

Since the entry of the white man into southern California, the demand for water for both domestic and irrigation needs has steadily increased. During the past 20 years there has been a constant over-draft of the natural supply of both underground and surface waters in the Los Angeles area. Consequently, all water users are greatly disturbed over the great loss of water which occurs when mud-laden floods from burned areas are permitted to escape to the ocean. If these waters could be kept clear, they could be conserved by percolation into underground reservoirs through the various systems of water-spreading which have been developed in the piedmont area. Where surface reservoirs have been developed by the construction of costly dams in the mountain canyons, these investments are decimated by the deposition of sediment eroded from burned watershed areas. The silt-life of these reservoirs would be greatly prolonged if fires could be kept out of the watersheds and the water entering them kept clear. This situation in southern California can be summed up by the statement that clear and regulated surface run-off water is usable water, while mud-laden flood waters are wasted water.

A good cover of vegetation in the watersheds, by preventing excessive erosion, keeps the surface run-off water clear and usable, and may therefore be regarded as a powerful agency of water conservation in

southern California. The inference is clear that for both flood control and water conservation purposes, preservation of the forest cover in the mountain watersheds should be made an integral part of any comprehensive management plan.

Since 1927 the California Forest and Range Experiment Station has carried on studies in the laboratory and in the field which are designed to explain how and to what extent vegetation influences the water cycle and erosion. The objectives have been, first to determine the interrelation of vegetation, soil, water and climate, and then to develop for various types of vegetation such methods of watershed management as will yield the maximum quantity of usable water. In the ultimate management of a watershed area there is involved not only protection of the native vegetation, but possibly manipulation of that vegetation or alteration of the cover by the planting of additional vegetation which may be different from the original cover, either for temporary or permanent occupancy of the land. With respect to southern California these studies are now being largely concentrated in a section of the Angeles National Forest especially set aside for the purpose and designated as the San Dimas Experimental Forest. This area, containing a total of 17,000 acres, embraces the entire watersheds of San Dimas and Dalton Canyons above the flood control dams maintained in these canyons by the Los Angeles County Flood Control District. A detailed description of this large watershed laboratory is contained in the 16-page pamphlet entitled "The San Dimas Experimental Forest," a copy of which is submitted as an integral part of this statement.

Although the Experimental Forest is still in the construction stage, preliminary results in the measurement of run-off and erosion from small controlled watersheds within the area have been obtained and may be of considerable use in determining run-off and erosion rates from well-forested watershed areas. These results are of special interest in comparison with the behavior of run-off from the Mt. Lukens burned area. A mimeographed statement of 17 pages entitled "Run-off and Erosion Experiment in Mountain Areas," was prepared on March 14, 1935 to present to a conference of engineers some of the experimental results from the San Dimas Experimental Forest and other studies. The pamphlet also contains data from 1/50th acre plots designed to measure the erosion in burned areas (table 3 on page 7), comparison of erosion from burned and unburned plots 1/40 acre in size (table 4 on page 10), and also data from soil-tank studies designed to measure the influence of forest litter on run-off, percolation and erosion for different soil types (table 6 on page 15). This pamphlet also is submitted as an integral part of the present statement.

A careful study of the experimental data will show that these studies are gradually developing the explanation of how a vegetative cover actually functions in protecting soil surface against erosion, and in maintaining the soil surface favorable for the infiltration of rain water by means of a litter cover developed by the vegetation itself, and in consequence of these two actions exerts a cumulative effect in reducing run-off peaks and in maintaining run-off water in a clear and usable condition.

Plans for the future conduct of research in the San Dimas Experimental Forest are briefly outlined in the Forest pamphlet,

particularly on pages 3 to 8. Not mentioned in the pamphlet is a series of studies relating to planting of burned areas and fire-breaks for the purpose of controlling run-off and erosion and for preventing the spread of fires across the breaks. These studies are described briefly.

Planting burned watersheds. There has long been a general public misconception in southern California regarding the planting of burned areas to restore watershed cover, the usual idea being that such areas should be planted with trees. In order properly to appreciate this particular planting problem it is necessary to know something of the ecological requirements of trees in relation to the growing habits of the chaparral forest.

The chaparral cover of today although it appears broadly uniform is in fact a great mosaic of diverse sub-types which have been profoundly affected by past centuries of fires and erosion. These sub-types vary all the way from tall stands of oak with closed crown canopies down through mixtures of ceanothus, manzanita, sumac and chamise, to thin, low stands of wild buckwheat and sage. In this list, from the standpoint of good forest cover, oak may be regarded as the highest form, occupying the best sites, and buckwheat and sage the lowest, growing on the driest and most severe sites. Moreover, the "types" are not stable but are in a continual state of change, progressing upward towards the tree-like forms or degenerating towards the sub-shrub types. In this process fire, with its usual concomitant erosion, is the most potent degenerative influence, and absence of fire the necessary condition for upward progression.

Repeated fire and erosion bring about progressive deterioration in the chaparral cover due not only to the fire damage but also to the impoverishment of the site by loss of top soil. After each setback, recovery of the original type is slower and more difficult and, once a type has been depressed by several stages, nature's effort to regain the original type may require hundreds if not thousands of years of slow soil building. In other words, retrogression may be rapid but recovery to the original condition is extremely slow, because the return must be made by gradual progression through all the lost steps.

With this picture clearly in mind, it will be at once appreciated that when we plant trees on burned brush areas we are attempting to do in one step what nature ordinarily would require a century or more to do. We are expecting the highest plant type to succeed on sites suitable only for mediocre or lower plant types. This explains the poor results that have attended protracted efforts at wholesale displacement of the chaparral type with pine. Exceptions are to be noted of course, as in especially favorable sites or where special care in maintaining the plantations can be justified on grounds other than that of improving the watershed cover. Also, at higher elevations within the conifer zone, the planting of conifers is feasible and appropriate to maintain that type against the encroachment of chaparral following fire.

The native chaparral under ordinary conditions has a strong power of recovery within a few years after burning. Planted trees, however, grow much more slowly than most people suppose, especially during their early years. Hence the wholesale planting of trees in the chaparral type has been found by experience to be uneconomic and

futile; uneconomic because the cost, (including labor and nursery stock,) reaches the exorbitant figure of $30 to $100 per acre depending on the roughness of the topography, and because the survival of the planted trees is usually so low that only a feeble and scattered cover is obtained; futile because the native chaparral itself invariably recovers more rapidly than the planted trees can grow, with the result that the trees are crowded out during the early period of their growth if indeed they do not succumb to the high temperatures and severe drought of the long summer months.

Sowing of Mustard on Burned Areas. There is a period, however, between denudation by fire and the satisfactory recovery of the chaparral, usually 3 to 5 years (or much longer in the case of very severe fires) when the soil is exposed to severe erosion between the shrub stumps. In order to secure a vegetative cover on these inter-shrub spaces as quickly as possible after a fire, the Forest Service has borrowed from agriculture the idea of sowing a quick-growing cover-crop on the burned area. The testing of various types of plants early indicated that common mustard was best adapted to this purpose. A list of the qualities which are required of the plants for this use explains why mustard has proven effective:

The seed must be available in large quantities, meaning tons rather than pounds.

The seed must germinate and establish itself after broadcasting on the surface, since it is impossible to cultivate the steep mountain slopes.

The seed must germinate rapidly after the early fall rains and continue to grow during warm periods in the winter months.

The seed must be reasonably small and light in weight so that the large quantities needed can be easily transported over the mountain areas.

On the negative side the plant species should not be a serious weed pest.

In addition to these qualities, all of which the mustard possesses, the mustard also has the following advantages: After germination it produces a large rosette of basal leaves spreading in a circle 10 to 20 inches in diameter; 5 pounds of mustard seed per acre are sufficient to produce a dense cover on any area where the soil is reasonably receptive; the mustard reaches full maturity in early summer; it produces an abundant seed-crop which in one season increases from 50 to 200-fold the amount of seed originally sown; the spherical mustard seeds feed easily through funnels and hoppers and can therefore readily be sown from airplanes over inaccessible or remote areas; the seed is cheap, being obtainable at prices ranging from 5 to 10 cents per pound in lots of as many tons as needed.

In actual performance in the field, detailed and laborious measurements on the Brown Mountain burned area above Pasadena, have shown that the average stand of mustard contained 6 plants per square foot, 36 to 50 inches tall, and that over 5,000 pounds of oven-dry plant material was produced per acre and returned to the soil in the form of protective litter. We have as yet no <u>quantitative</u> measure of the effectiveness of mustard in holding soil or retarding run-off. It is obvious, however, that 5 or 6 plants per square foot of soil surface must inevitably have a strong effect in reducing both run-off and erosion. Regarding the future, the mustard will gradually yield as it is crowded out by the strong-growing native shrubs and

will remain only in open patches where shrubs have been completely killed by fire. Inevitably these openings also will be recaptured by chaparral if fires are prevented in the future. All the evidence to date indicates that the sowing of mustard is an effective and economic supplementary measure for reducing erosion and ameliorating flood conditions from burned watersheds.

Planting of Firebreaks. Many miles of firebreaks have been constructed in the mountain areas of southern California. These strips from which all the vegetation has been removed vary in width from 50 to 100 feet and where possible follow well defined ridges. Their principal function is to provide a means of access to firefighters and to establish points of attack for backfiring rather than the often over-emphasized purpose of directly stopping the spread of fire.

It is obviously necessary to keep these firebreaks denuded, which involves considerable maintenance due to the rapid growth of annual grasses and other vegetation that becomes highly inflammable when dry. This removal of vegetation is undesirable from the standpoint of the erosion which results in certain locations and due to the distrubance of aesthetic values caused by these cleared strips. For several years this Experiment Station has searched for and tested numerous plants of low inflammability for the planting of firebreaks in southern California. The requirements for survival against summer drought, freezing temperatures in winter and attack by rodents have eliminated most of the species considered. Twelve of the most promising succulent species are now being planted at selected sites from approximately one to five thousand feet elevation on the San Dimas Experimental area as a continuation of this investigation.

The use of "non-inflammable" low growing plants capable of producing a solid, compact evergreen cover to replace the highly inflammable herbs and grasses which normally occur on firebreaks would reduce maintenance costs and erosion, and would also help to preserve the scenic value of the mountain areas.

Protection of the Vegetative Cover. The importance of maintaining a cover of chaparral or other vegetation on the mountainous portions of the drainage basins under consideration has been indicated in preceding pages of this statement. The most feasible means now available for the accomplishment of this objective is by increasing its protection from fire. This protection in adequate form should be given due consideration in formulating a comprehensive plan of flood control for Los Angeles County.

CHARLES J. KRAEBEL
Senior Silviculturist

Arroyo Seco Creek showing highest stage (white cord) reached during 12-inch rain of December 31, 1934, a "regulated" flow from a well-forested watershed tributary to Los Angeles River.

Channel of Pickens Canyon showing run-off results of the same storm from a fire-denuded watershed. Upper tape shows flood crest, middle tape pre-storm channel bottom, lower tape post-storm bottom.

THE SAN DIMAS EXPERIMENTAL FOREST

CALIFORNIA FOREST and RANGE EXPERIMENT STATION
FOREST SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

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The San Dimas Experimental Forest

Dedicated to the Pursuit of Studies in the Management of Chaparral Watersheds for the Maximum Yield of Useful Water and for other Human Benefits

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I. The Problem of Watershed Management in Southern California.

The yield of usable water from the chaparral covered mountains of Southern California is of vital importance to the rural and urban populations that occupy the valleys adjacent to these watershed areas. During the past half century domestic, industrial and agricultural demands for water in this semi-arid region have reached a point far in excess of the normal supply, as indicated by declining water tables in alluvial filled basins underlying the valley floors. These natural underground basins form an ideal system of storage and distribution of water and are normally replenished by flows from the mountain areas.

The problem of providing an adequate amount of usable water to meet present and future needs is accentuated by the excess of demand over present local supplies. This shortage has led to the importation of water from other regions at great cost, which factor limits its agricultural use. The problem is made more difficult by unequal seasonal distribution of rainfall, characteristic of the region. Rains confined almost entirely to the winter season frequently occur as torrential downpours for which it is difficult to provide sufficient storage by engineering means, and which unless stored, waste to the sea, lost for use as well as creating in transit a very serious hazard to life and property.

Accessory to the problem of flood control is that of controlling soil erosion, which as an accompaniment of excessive run-off may render the water supplied by storms unusable for human consumption. Erosion also results in the silting of storage and flood control reservoirs, in the clogging of gravels in water spreading grounds, and adds much to the danger inherent in floods. This erosion may be a result either of burning of vegetation on the watersheds or of soil disturbance by such a cause as road construction.

It is recognized that the existing chaparral vegetation has an important influence in reducing the magnitude of floods and erosion. At the same time this vegetation takes its toll in consumption of water. This leads to the problem of increasing the yield of usable water by some method of systematic management of the watershed vegetation consistent with the control of floods and erosion.

The watersheds of the San Gabriel, San Bernardino and San Jacinto ranges furnish most of the local water available to Southern California. Since these areas occur largely within National Forests, their management for maximum productivity is of concern to the United States Forest Service. A comprehensive investigation of problems in watershed management in the chaparral region has been initiated by the California Forest and Range Experiment Station. A large part of the work is being concentrated in the San Dimas Experimental Forest which has been specially set aside for that purpose.

The preliminary planning and initiation of work on the Experimental Forest was done under the leadership of Dr. W. C. Lowdermilk, who left the Forest Service in 1933 to become Vice-Director of the Soil Conservation Service. Mr. E. N. Munns, now of the Washington Office of the Forest Service, who began studies in forest influences in Southern California 25 years ago, has contributed much in shaping the present watershed research program. The project, particularly the development and protection of the San Dimas Ex-

perimental Forest, is being carried on in close co-operation with the Administrative Divisions of the Forest Service through the Supervisor of the Angeles National Forest. The dams and other major engineering features have been designed and built under the supervision of the Regional Engineer from the office of the Regional Forester.

II. The Experimental Area.

The San Dimas Experimental Forest is situated in the Sierra Madre Mountains northeast of Glendora, California, within the boundaries of the Angeles National Forest. It has an area of approximately 17,000 acres, including the drainage basins of Big Dalton and San Dimas Canyons tributary to the San Gabriel Valley.

The investigations to be conducted on the Forest have, in general, a two-fold purpose: first, to make a quantitative determination of the relation of chaparral vegetation to the yield of usable water from mountain watersheds and of its function in reducing erosion; second, to develop methods of management or treatment of the vegetation in order to obtain a maximum yield of usable water with a minimum amount of erosion.

The information required for the solution of these problems is as follows:

1. Exact measurement of precipitation on mountain drainage basins;
2. Measurement of yield of water and debris from typical watersheds with varying types of vegetative cover;
3. Analysis of the types of vegetation involved in water losses and control of erosion on mountain watersheds;
4. Determination of the consumption of water by native vegetation and by types of vegetation which might be substituted for the native chaparral; and

5. Quantitative determination of the environmental factors affecting water use by vegetation.

These problems are being attacked by a system of studies in which vegetation-water relationships are investigated in progressive degrees of intensity. The experimental units involved (refer table, page 12, and map, pages 10 and 11) are:

1. MAJOR AND INTERMEDIATE WATERSHEDS:

To measure the summed effect of all environmental factors on rainfall-run-off and erosion relationships. The major watersheds consist of the whole San Dimas and Big Dalton drainages, which are sub-divided into ten intermediate compartment watersheds, ranging in area from one to fourteen square miles.

Rainfall is measured very accurately by rain gages spaced one-half mile apart mainly on a system of trails located on contours at elevations of 2100, 3100, 4100 and 5100 feet. These rain gages, some 370 in number, are read at the end of each storm.

Records of the rate of rainfall are obtained by fifteen intensity rain gages which automatically record the rate and amount of precipitation on a chart. These gages are distributed throughout the area as equally as possible, both by altitude and by intermediate watersheds.

Streamflow resulting from the rainfall is measured at the mouth of each intermediate watershed by means of control flumes of various sizes for flood flows, and 90° V-notch weirs for ordinary flows. (See Plate, page 13.)

The sum of all these stream gaging stations will give the total streamflow from the experimental area, which may be checked by reservoir records at the Los Angeles County Flood Control Dams near the mouths of the Big Dalton and San Dimas drainages. (Plate page 13.)

Surveys have been made of the Big Dalton and San Dimas reservoirs. Periodic re-surveys will show the amount of debris deposited in them as the result of erosion on the major areas.

2. SMALL WATERSHEDS:

A group of small watersheds of similar environmental characteristics, in which the factor of vegetation is isolated by treatment. It is planned to leave one watershed with its present vegetation undisturbed, and to burn the other two, keeping one denuded by repeated burning and allowing the other to return to normal plant cover after the single burning. The difference in the yield of water and debris between burned and unburned watersheds should evaluate the effect of vegetation on these two watershed products.

There are two sets of small watersheds on the Forest: one (Bell Canyon) at elevations between 2500 and 3400 feet, and the other (Fern Canyon) between elevations of 4500 and 5400 feet (Plates, pages 14 and 15).

These small watersheds are equipped with much more elaborate and intensive means of measuring rainfall, run-off and erosion than have been provided in the intermediate watersheds.

A concrete dam and a concrete lined reservoir have been built at the mouth of each small watershed. These structures are to catch debris eroded from each watershed. A 3-foot control flume and a 90° V-notch weir are used to measure the run-off (Plate, page 16).

3. RUN-OFF AND EROSION PLOTS:

Miniature areas on which are measured precipitation and surface run-off from small segments of a watershed under denuded and normally vegetated conditions. At present, the Forest contains three sets of plots located at elevations of 1500, 2700 and 5000 feet and containing vegetation typical of these altitudes. One installation consists of four 1/40-acre

plots, two with normal chaparral cover, and two kept denuded by burning (Plate, page 17.) The other two sets, totalling 18 plots, contain three groups each of three plots: one group to be kept with normal cover, one continuously denuded, and one denuded and then allowed to return to natural chaparral cover. The latter sets of plots are now being calibrated during an initial period of several years before treatment of the vegetative cover is started.

The run-off from each plot is measured by catching the water in a concrete trough at the base of the plot and running it through a specially designed tipping bucket which catches 1/10 cubic foot of water, then dumps it and brings another bucket into position. Each movement of the bucket on each plot is recorded electrically on a moving strip chart synchronously with a record of the rainfall. Later inspection of the chart permits a comparison of the rate of run-off from the denuded, succession and natural plots in relation to rainfall.

4. Road-fill Erosion Control Plots:

A series of rectangular areas on a road-fill, bounded by border strips, on which are tested various methods of controlling erosion from fill slopes. Eroded material is caught and measured in bins at the foot of each plot. On the Experimental Forest there is one set of seven road-fill plots, each 1/50 acre in area, at the head of Volfe Canyon. On these are studied the efficiency of erosion-control methods such as brush wattles of varying design, in conjunction with the sowing of grains and planting of cuttings of sprouting species as well as spreading the surface with hay (Plate, page 17).

5. Firebreak Succulent Plots:

Six plots, covering a range of elevations from 1500 to 5000 feet, have been established within the Experimental Forest for the study of succulent plants of low inflammability suitable for planting on firebreaks. The purpose of this study is to deter-

mine the feasibility of establishing a fire resistant cover, thereby reducing maintenance costs and erosion from these normally denuded strips. In each plot, which is fenced to keep out rabbits and larger animals, are planted twelve different species of succulents which might be suitable for firebreak planting; and a study is being made of their relative values, based on survival, rate of growth, and other criteria.

6. LYSIMETERS:

Impervious concrete or metal tanks of various dimensions which when filled with soil, are used to grow plants varying in size from grass up to trees. Their purpose is to determine the relative rates of water consumption by transpiration of various plant species, and the effect of these species on rates of water percolation through the soil. The following lysimeter installations are being completed near Tanbark Flat:

a. A series of 50 small metal lysimeters, each with a capacity of 300 pounds of soil, for the purpose of evaluating, by weight, day by day losses due to transpiration and evaporation.

b. Thirty medium-sized metal tanks, each with a capacity of 1800 pounds of soil. These instruments allow observations on the water cycle to be made both by weight and by volumetric measurement of percolation and run-off.

c. A group of 26 large concrete lysimeters, each having surface dimensions of 10.5 by 21 feet and a depth of six feet, are for the purpose of studying the water cycle with larger masses of soil and vegetation, using longer growth rotations. Provision is being made for the measurement of both intensity and amount of rainfall, run-off and percolation. (See diagram, page 19.)

7. CLIMATIC STATIONS:

The Forest contains four complete stations located at elevations of 1500, 2700, 4350 and 5100 feet. These possess the following instruments for measuring climatic and soil environmental factors; air hygrothermograph, soil thermograph, air and soil thermometers, psychrometers, anemometer, wind di-

rection transmitter, evaporation pans and atmometers (Plate, page 18). Two stations, less elaborately equipped, are located in Bell Canyon watershed No. 2 and No. 4, at 2800 feet elevation. The latter is planned to measure environmental influence before and after the watershed is burned, while the former is to serve as a check. Installation of several more stations is contemplated to complete the range from the valley floor to timberline.

8. Ecological Studies:

A detailed type map is being made of the existing vegetation in each watershed, together with a statistical analysis of each vegetation type to depict its species composition and cover density. Phenological observations are carried on continuously at 14 carefully selected typical stations. To determine the biological factors affecting the water cycle, a study is being made also of the fauna of the Experimental Forest.

9. Geological and Soils Studies:

To complete the picture of environmental influences, surveys are being made of the geology of the Forest and of its soil types.

10. Headquarters Facilities:

Since the solution of problems involved in this investigation is expected to require a period of thirty years or more, a complete field headquarters has been constructed at Tanbark Flat, in the San Dimas drainage. Permanent facilities have been set up here for the conduct of experimental work and the housing of technical personnel. These include dwellings, laboratory, garage, shop, power plant and stable (Plate, page 18). Tanbark Flat was formerly the site of an experimental nursery conducted by the Los Angeles County Forestry Department. The extensive groves of coniferous trees which were planted around that nursery now form an attractive setting for the Experimental Forest headquarters. In addition to the necessary roads and trails, communication with all parts of the Experimental Forest is provided by a telephone system connecting the headquarters with all stream-gaging stations and other major installations.

ACKNOWLEDGMENTS

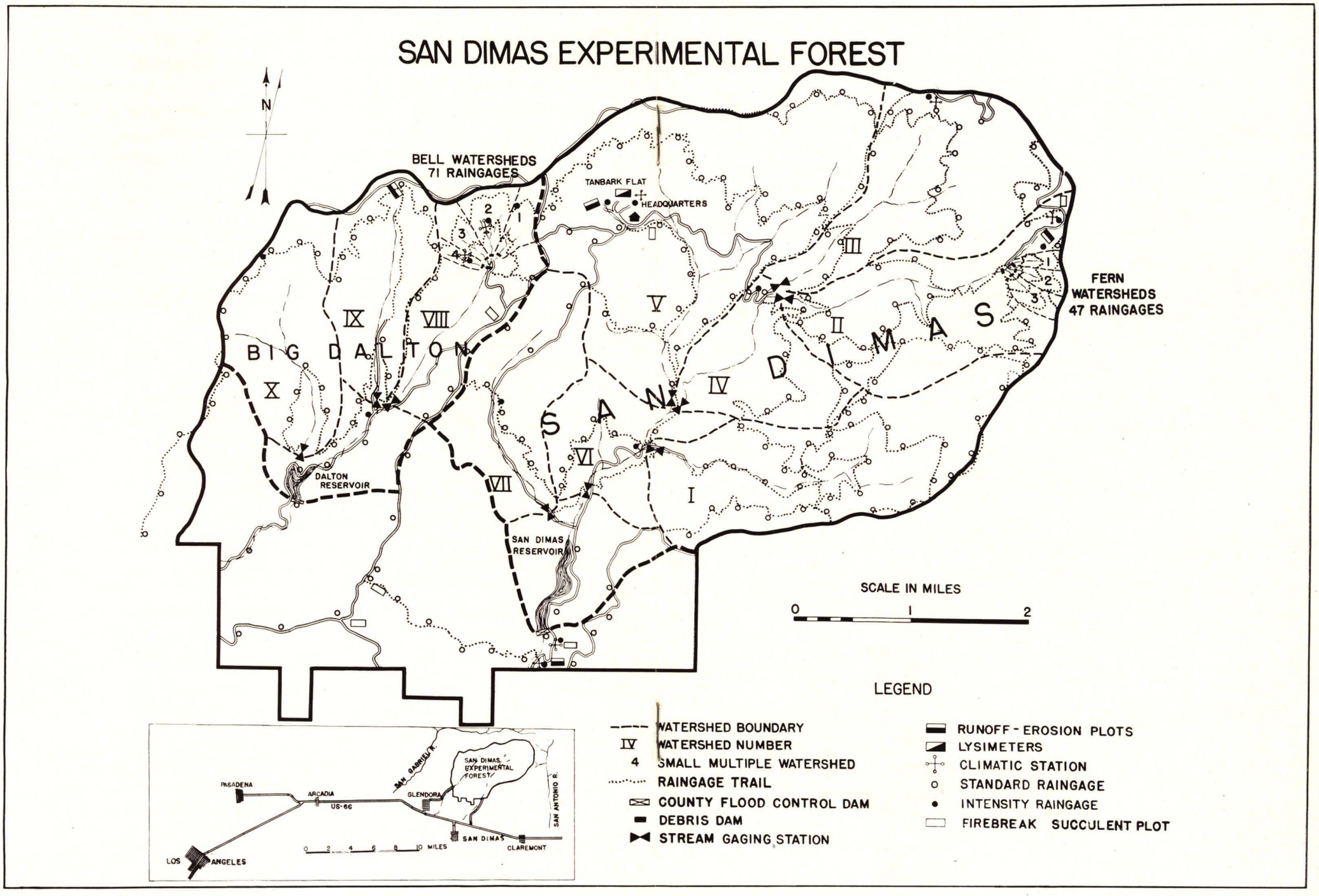
The Experimental Forest owes its present advanced development to the helpful cooperation of many agencies and individuals. Assistance has flowed to the project from so many sources and in such diverse ways that any acknowledgment must inevitably be incomplete. Whether in shaping the broad plan of study, in critically reviewing some detail of experimental technique, or in the actual lending of equipment and facilities, the following list of participants reflects the wide interest of the community in the Experimental Forest:

Angeles Forest Protective Association.
California Institute of Technology.
California State Chamber of Commerce (Conservation Department).
California State Division of Forestry.
Carnegie Institution of Washington.
City of Glendora.
Conservation Association of Los Angeles County.
Los Angeles Chamber of Commerce (Agricultural Dept.).
Los Angeles County Board of Supervisors.
Los Angeles County Flood Control District.
Los Angeles County Forestry Department.
Pasadena City Water Department.
San Dimas Water Company.
San Gabriel Valley Associated Chambers of Commerce.
University of California (especially the faculties of Forestry, Engineering, and Agriculture).

Among federal bureaus with which the project is mutually articulated are the Bureau of Agricultural Engineering, Geological Survey, Soil Conservation Service and Weather Bureau.

In addition, many individual engineers and scientists not in public employ have given liberally of their counsel and constructive criticism.

Finally, emphasis must be laid upon the fact that the heavy construction involved in shaping this forest area into an adequate watershed laboratory has been made possible only through the substantial aid of the Civilian Conservation Corps, the Works Progress Administration and other national emergency relief agencies.

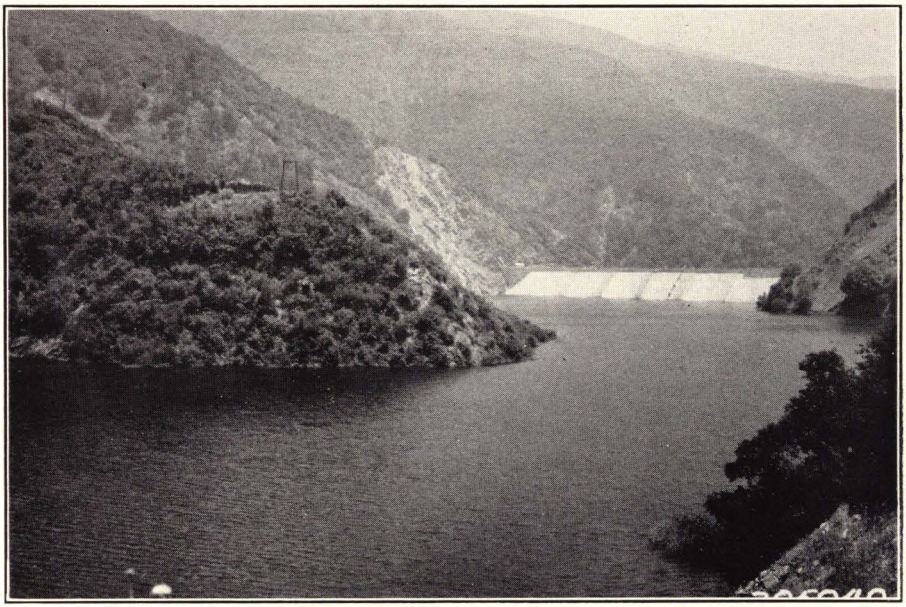

SAN DIMAS EXPERIMENTAL FOREST
N
BELL WATERSHEDS
71 RAINGAGES
TANBARK FLAT
HEADQUARTERS
FERN
WATERSHEDS
47 RAINGAGES
BIG DALTON
SAN DIMAS
DALTON
RESERVOIR
SAN DIMAS
RESERVOIR
SCALE IN MILES
0 1 2
LEGEND
WATERSHED BOUNDARY
WATERSHED NUMBER
SMALL MULTIPLE WATERSHED
RAINGAGE TRAIL
COUNTY FLOOD CONTROL DAM
DEBRIS DAM
STREAM GAGING STATION
RUNOFF - EROSION PLOTS
LYSIMETERS
CLIMATIC STATION
STANDARD RAINGAGE
INTENSITY RAINGAGE
FIREBREAK SUCCULENT PLOT
SAN GABRIEL R.
SAN DIMAS EXPERIMENTAL FOREST
PASADENA
ARCADIA
US-66
GLENDORA
SAN ANTONIO R.
SAN DIMAS
CLAREMONT
LOS ANGELES
0 2 4 6 8 10 MILES

SAN DIMAS EXPERIMENTAL FOREST
DESCRIPTIVE DATA: MAJOR, INTERMEDIATE AND SMALL WATERSHEDS

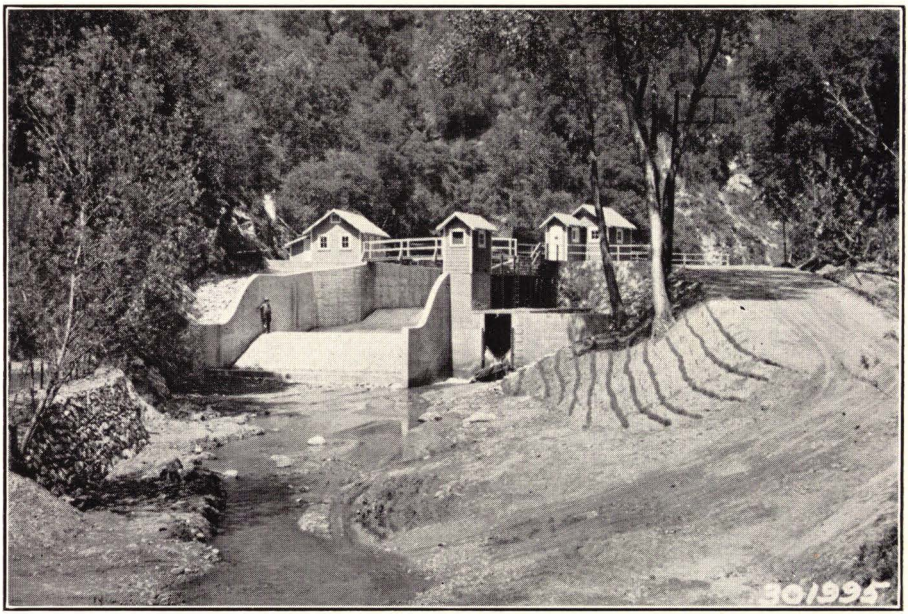
Watershed	Area Square Miles	Area Acres	Range in Elevation, Feet	Number Rain Gages		Stream Gaging Stations			Reservoir Capacities	Dam Description
				Standard	Intensity	Type	Width Flume	Capacity Sec. Ft.		
Major									(Acre Ft.)	
San Dimas	15.96	10,210	1500-5500	174	10				1,820	Gravity*
Big Dalton	4.25	2,720	1700-3500	102	5				1,160	Multiple arch*
Intermediate										
San Dimas Drainage										
I Wolfskill	2.78	1,780	1700-5200	18	1		10	520		
II Fern	2.29	1,465	2600-5500	14	2		10	500		
III Upper E. Fork	2.28	1,460	2600-5200	15	1		10	580		
IV East Fork	5.74	3,675	1900-5500	33	3		15	1,375		
V North Fork	4.75	3,040	1900-4500	35	2		15	1,160		
VI Main Fork	14.30	9,150	1600-4500	94	9		30	3,520		
VII West Fork	1.66	1,060	1600-3100	10	1		10	450		
Dalton Drainage										
VIII Bell	1.40	895	1900-3500	9	3		10	350		
IX Volfe	1.29	825	1900-3500	11	1		8	250		
X Monroe	1.56	1,000	1800-3400	16	1		10	350		
Small									(Cu. Ft.)	
Bell No. 1	0.121	77	2500-3400	18	1		3	50	10,500	Ambursen
No. 2	0.158	101	2500-3500	23	1		3	50	10,500	Ambursen
No. 3	0.097	62	2500-3400	16	0		3	50	10,000	Ambursen
No. 4	0.058	37	2500-3100	14	1		3	50	100,000	Ambursen
Supplementary									325,000	Ambursen**
Fern No. 1	0.055	35	4500-5400	13	1		3	50	8,500	Ambursen
No. 2	0.063	40	4500-5400	16	0		3	50	10,000	Ambursen
No. 3	0.084	53	4500-5400	18	0		3	50	10,000	Ambursen
Supplementary									85,000	Single arch

Combination of control flume and 90° V-notch weir, with automatic time-stage recorders and electric depth gauges.

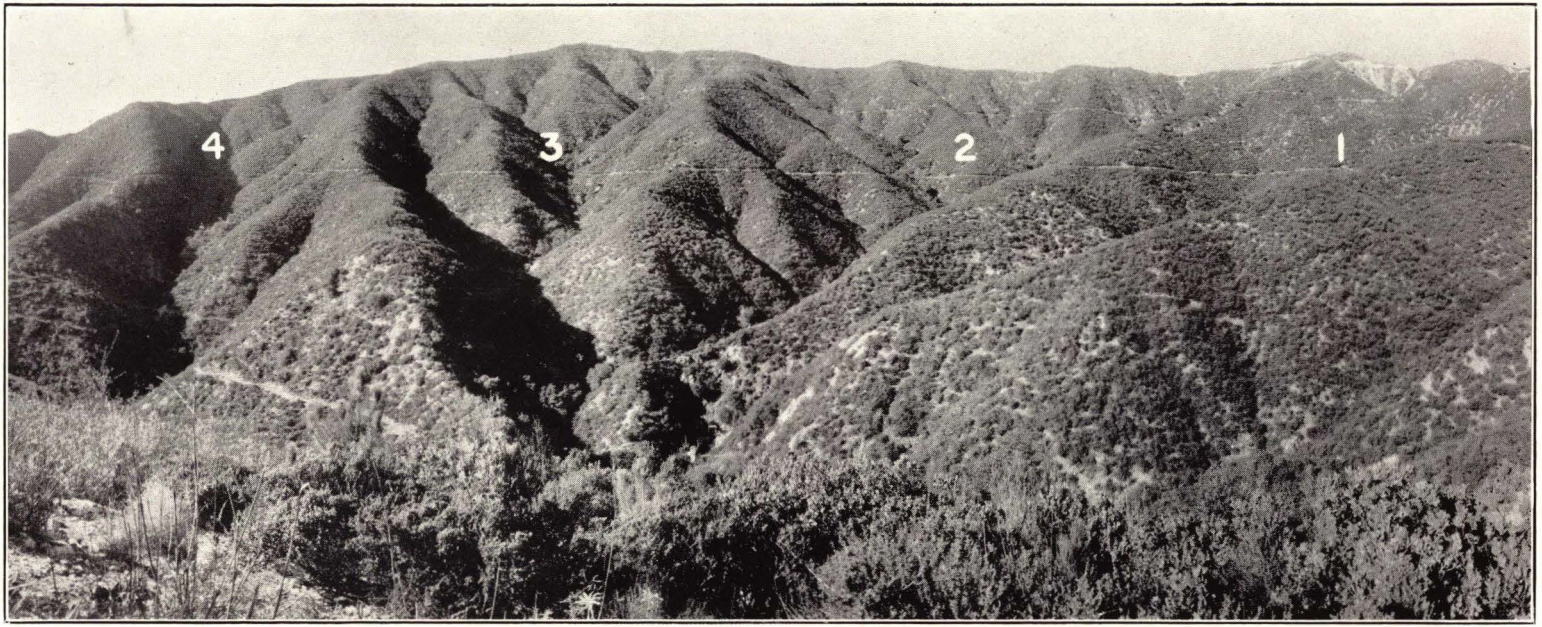
*Los Angeles County Flood Control.
**Ambursen—earth fill.



Big Dalton Reservoir and Dam built by Los Angeles County Flood Control District. This structure provides a master control for Big Dalton Canyon, a major watershed on the San Dimas area.



Stream gaging station near the mouth of the main San Dimas Canyon Watershed No. 6. A modified Parshall flume with 30-foot throat for measuring flood flows. 90° V-notch weir for measuring low flows shown at right. Measuring range 0.005 to 3520 cubic feet per second.

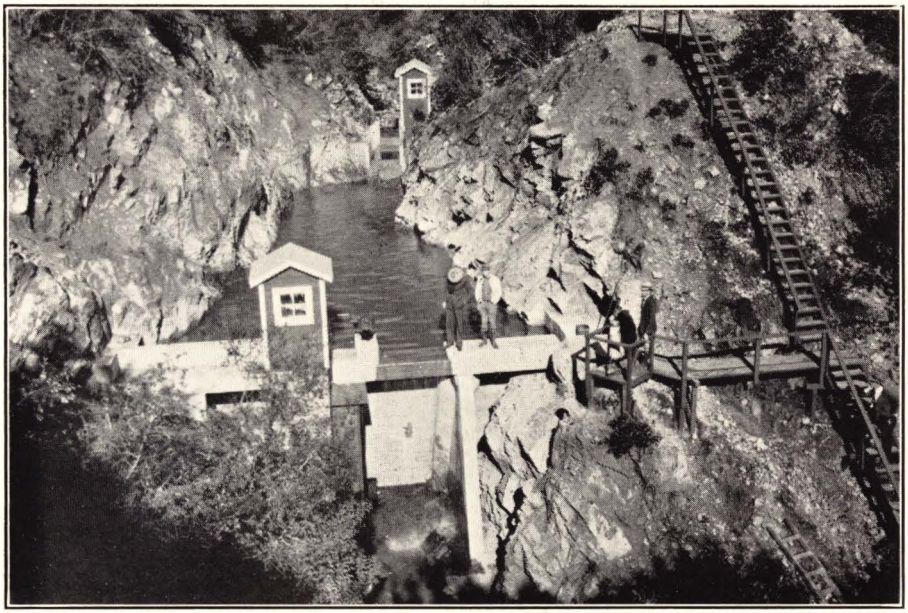


BELL SMALL MULTIPLE WATERSHEDS

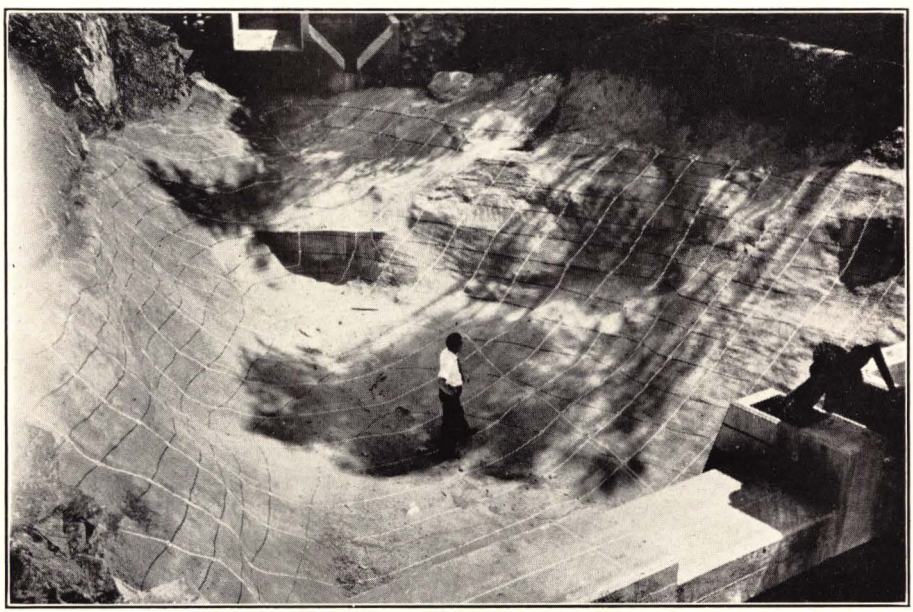
Area burned in 1919. 71 *rain gages are located on contour trails at* 2500, 2800, 3100 *and* 3400 *feet elevations. Total area* 277 *acres.*

FERN SMALL MULTIPLE WATERSHEDS

Vegetation unburned for past 50 years. 47 rain gages are located on contour trails at 4700, 4950 and 5200-foot elevations on total area of 128 acres.

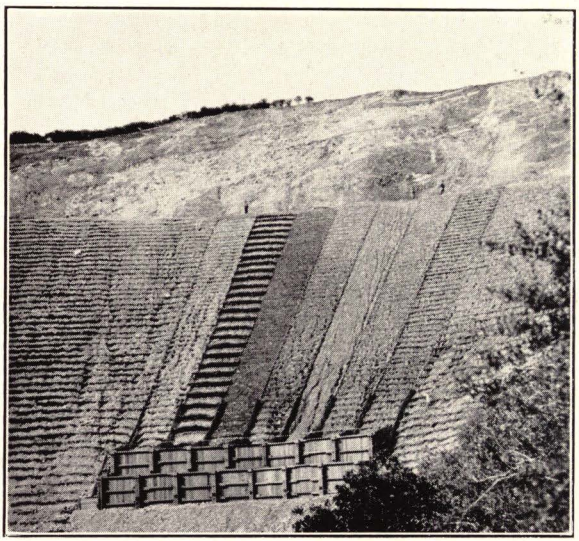


Installation at mouth of Bell Watershed No. 2. Ambursen type dam used to catch eroded material from 101-acre watershed. Gaging station at head of reservoir provides continuous record of run-off. This installation is typical of six controls for Bell and Fern Watersheds.

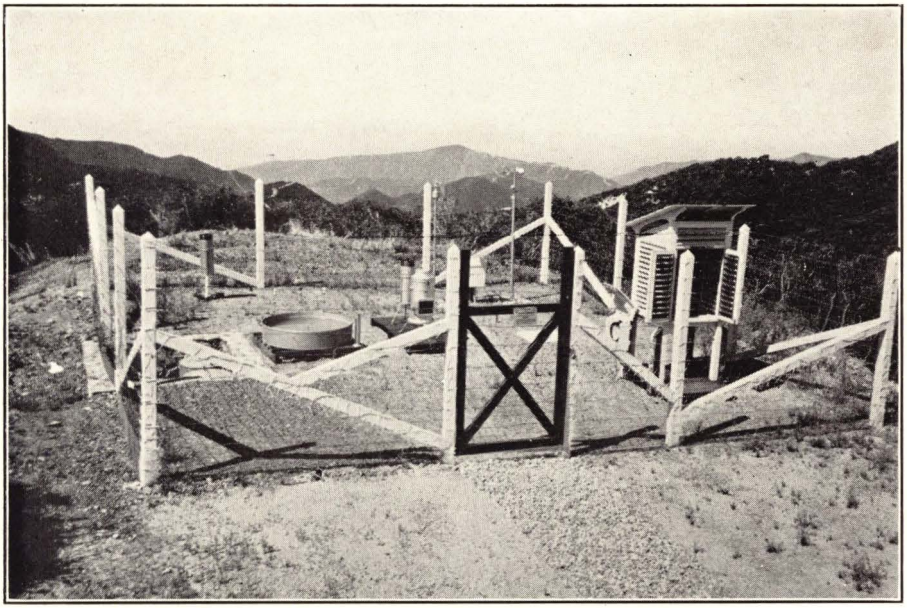


Reservoir at the mouth of Fern Watershed No. 1, thirty-five acres. Three-foot Parshall flume for measuring flood flows and 90° V-notch weir for measuring small flows are shown in the background. One-foot contours and two-foot transverse ribs painted on the gunite lining aid in measuring debris.

San Dimas Run-off and Erosion Plots. Annually denuded plots (1/40th acre each) about to be reburned. A pair of plots identical in size are located in original brush cover at left. The rainfall and run-off are measured continuously through tipping bucket devices and recorded electrically on a strip chart. Eroded material is collected in a trough and silt trap at the lower end of each plot.



Volfe Canyon Road Slope Erosion Control Experimental Plots. The effectiveness of various methods of slope fixation is under observation and the erosion from each plot measured in bins at the base of the fill.

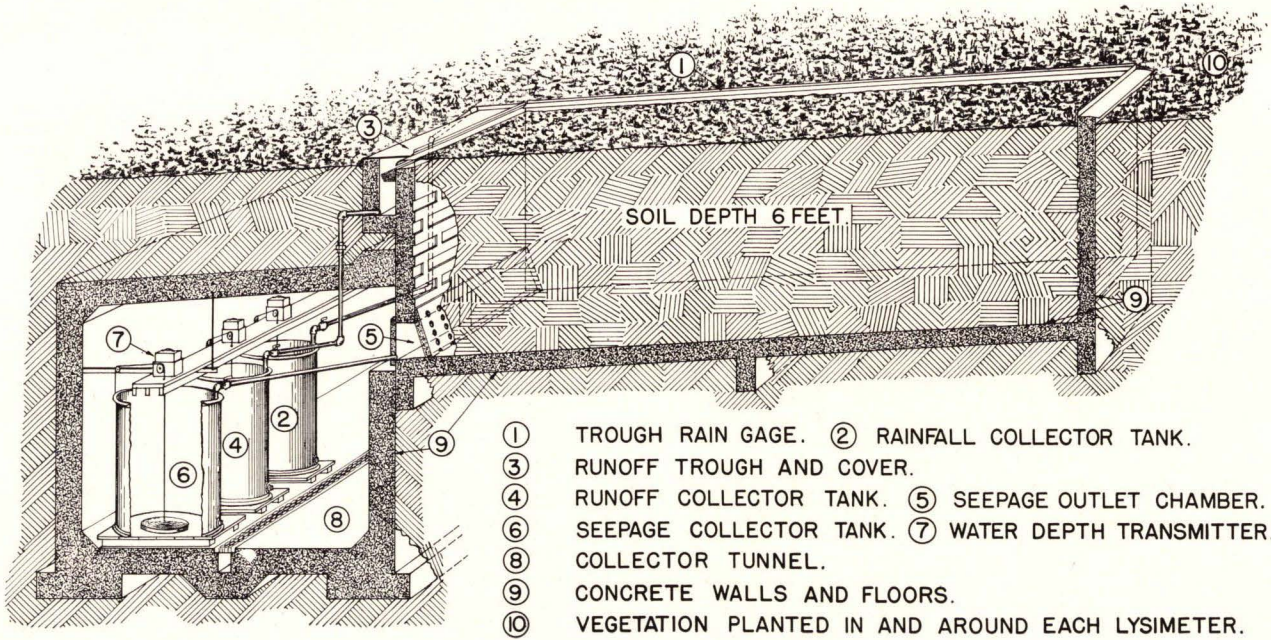


Climatic Station at 4350 feet altitude equipped for measurement of environmental factors of air and soil.

Dormitory for technical assistants at field headquarters of the Experimental Forest, Tanbark Flat.

DIAGRAM OF A SINGLE LARGE LYSIMETER

SURFACE AREA 5-MILACRES (10½ X 21 FEET.)



① TROUGH RAIN GAGE. ② RAINFALL COLLECTOR TANK.
③ RUNOFF TROUGH AND COVER.
④ RUNOFF COLLECTOR TANK. ⑤ SEEPAGE OUTLET CHAMBER.
⑥ SEEPAGE COLLECTOR TANK. ⑦ WATER DEPTH TRANSMITTER.
⑧ COLLECTOR TUNNEL.
⑨ CONCRETE WALLS AND FLOORS.
⑩ VEGETATION PLANTED IN AND AROUND EACH LYSIMETER.

CALIFORNIA FOREST AND RANGE
EXPERIMENT STATION

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C. J. KRAEBEL, *Senior Silviculturist, Project Leader*

SAN DIMAS EXPERIMENTAL FOREST

J. D. SINCLAIR, *Silviculturist, in Charge*

Circular prepared by
EXPERIMENTAL FOREST STAFF
June, 1935; Revised June, 1936

RS
I-1
Watershed Studies

March 14, 1935

RUNOFF AND EROSION EXPERIMENTS IN MOUNTAIN AREAS[1]

C. J. Kraebel, Senior Silviculturist
California Forest and Range Experiment Station

In his introductory paper Mr. Kotok outlined briefly some of the methods of study employed by the California Forest and Range Experiment Station in its attack on the problems of runoff and erosion in mountain areas.[2] It is the purpose of this paper to present a few representative results of those studies which might be of general interest for the trends which they indicate.

Runoff and Erosion from small Chaparral Watersheds.

The records given from unburned areas are measured quantities from six small watersheds in the San Dimas Experimental Forest in the San Gabriel Mountains of southern California. Rainfall is measured in 104 standard rain gages and one intensity gage on the 370 acres embraced in these six watersheds. Runoff is measured for each watershed through a modified Parshall flume for large flows, and a 90° V-notch weir for small flows. Erosion is measured in a gunnited reservoir formed by an Ambursen type dam at the mouth of each canyon. Check measurements of runoff are made possible by water stage recorders attached to the reservoirs.

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1. Presented before a Progressive Conference on Water Conservation held under the auspices of the Los Angeles Section, American Society of Civil Engineers, at Biltmore Hotel, Los Angeles, California, March 13-14, 1935.
2. Earlier results of these studies have been reported (see page 17) by Dr. W. C. Lowdermilk, who was largely responsible for planning and initiating the work during his active connection with the Station as Senior Silviculturist. Dr. Lowdermilk, now on furlough from the Station, is serving as Vice-Director of the Soil Erosion Service, Dept. of the Interior.

For the burned watershed,[3] precipitation and runoff data were obtained from the Los Angeles County Flood Control District. Rainfall was estimated from the records of 3 intensity gages within a radius of 3 miles of the watershed. Runoff figures are calculations from data on surface velocities and stages obtained by a field party during the flood. Erosion was calculated from 1/50-acre Experiment Station plots at the head of Pickens Canyon, directly north of the village of Montrose.

All figures given are for a typical storm of the 1934 season.

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3. The significance of comparing burned and unburned watersheds is that burned areas, in southern California at least, are more or less completely denuded of vegetation by fire, while most areas unburned for upwards of 20 years are not only covered with vegetation from 6 to 15 feet high but have also a ground cover of litter and humus which increases penetration of water into the soil as well as delays surface runoff.

Runoff and Erosion Experiments in Mountain Areas.
By C. J. Kraebel.

Table 1

RUNOFF AND EROSION FROM SMALL WATERSHEDS

Storm of December 12-15, 1934

Watershed	Area in sq. mi.	Runoff peak sec. ft. per sq. mi.	Precipitation: Total inches	Precipitation: Intensity in inches per hour: 30 Min.	Precipitation: Intensity in inches per hour: 1 Hour	Erosion rate cu. yds. per sq. mi.
WATERSHEDS WITH CHAPARRAL AND FOREST COVER INTACT						
Vegetation: mixed chaparral, chiefly Ceanothus, Adenostoma, and Quercus.						
Elev. 3000 ft.						
Bell No. 1	0.121	7.43	4.85	0.46	0.35	810(1)
Bell No. 2	.158	7.59	4.80	.46	.35	4
Bell No. 3	.097	7.02	5.14	.46	.35	36
Vegetation: chiefly Quercus, Ceanothus, and Pseudotsuga						
Elev. 5000 ft.						
Fern No. 1	.055	3.46	6.57	.52	.35	5.1
Fern No. 2	.063	3.13	6.62	.52	.35	2.1
Fern No. 3	.083	.77	6.47	.52	.35	2.9
WATERSHED DENUDED BY FIRE OF NOVEMBER 1933						
Former vegetation similar to that in Bell Watersheds						
Elev. 3000 ft.						
Halls Canyon	.84	1170	5.32	.64	.69	1400

(1) The extreme erosion in Bell Canyon No. 1 came directly from 2.5 acres of overcast slopes of a road crossing the head of this canyon - a striking illustration of the seriousness of road erosion in southern California. In the 1933-34 season the erosion rate from this same source amounted to 1040 cubic yards per square mile.

Runoff and Erosion from Intermediate and Large Chaparral Watersheds.

The records presented of rainfall and runoff from unburned areas are measured quantities from 3 watersheds, 2 intermediate and 1 large, in the San Dimas Experimental Forest. Rainfall is measured in 34 standard and 2 intensity rain gages on the intermediate watersheds and in 94 standard and 6 intensity rain gages on the large watershed, embracing 2230 and 9020 acres respectively. Runoff is measured for each watershed through a modified Parshall flume for large flows and a 90° V-notch weir for small flows. Erosion is not measured but is estimated for intermediate watersheds on the basis of Fern and Bell Canyon data.

For the burned areas, precipitation and runoff data were obtained from the Los Angeles County Flood Control District. Rainfall is measured in 3 intensity gages within or adjacent to the watersheds. Runoff figures are calculations from data on surface velocities and stages obtained by a field party during the flood. Erosion for Dunsmore was calculated from 1/50-acre Experiment Station plots in Haines Canyon, and for Pickens from similar plots in Pickens Canyon.

All figures given are for a typical storm of the 1934 season.

Table 2

RUNOFF AND EROSION FROM INTERMEDIATE AND LARGE WATERSHEDS

Storm of December 12-15,1934

Watershed	Area in sq. mi.	Runoff peak sec. ft. per sq. mi.	Precipitation			Erosion rate cu. yds. per sq. mi.
			Total inches	Intensity in inches per hour		
				30 Min.	1 Hour	
INTERMEDIATE WATERSHEDS WITH CHAPARRAL AND FOREST COVER INTACT						
Vegetation: mixed chaparral and spruce, chiefly Ceanothus, Adenostoma, Quercus and Pseudotsuga.						
Wolfskill Elev. 3500 ft.	2.08	2.25	4.52	0.52	0.35	50-(1)
Monroe Elev. 2500 ft.	1.40	3.82	4.99	.56	.43	50-(1)
INTERMEDIATE WATERSHEDS DENUDED BY FIRE OF NOVEMBER 1933						
Former vegetation similar to that in Wolfskill and Monroe Watersheds						
Dunsmere Elev. 3000 ft.	1.3	2090	5.52	.64	.69	2000(2)
Pickens Elev. 3000 ft.	1.33	1020	5.52	.64	.69	1400(2)
LARGE WATERSHED WITH CHAPARRAL AND FOREST COVER INTACT						
Vegetation: mixed chaparral and spruce, chiefly Ceanothus, Adenostoma, Quercus and Pseudotsuga.						
Main San Dimas Elev. 3500 ft.	14.09	3.28	4.90	.52	.35	No measurement.

(1) No measurement obtained, but normal erosion estimated at less than 50 cu. yds. per sq. mi. on basis of Fern and Bell Canyon data.

(2) Erosion estimated from plot data as explained on p. 4.

Erosion Quantities from One-fiftieth Acre plots in Burned Area.

Two pairs of bordered* plots were installed in the chaparral type of the San Gabriel Mountains in an area which had been burned over in November and subjected to heavy rains in December 1933. Each plot has a projectional area of 1/50-acre on slopes slightly above 60 per cent and is provided with silt traps at its foot to catch eroded soil. Rainfall is measured by one standard rain gage placed in the center of each pair of plots and by one intensity gage within a radius of one mile. Equipment for measuring runoff could not be provided on these isolated plots.

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* The plots were isolated from the surrounding hillside by means of boards, 10 inches wide, set on edge to a depth of 6 inches in the plot boundaries and joined by means of metal sleeves and elbows.

Table 3

EROSION QUANTITIES FROM ONE-FIFTIETH ACRE PLOTS IN BURNED AREA

Typical 1934 Storms - February to December, Inclusive

Plot location	1934 storms	Precipitation		Erosion rate cu. yds. per sq. mi.
		Total inches	Maximum intensity inches/hour	
Haines Canyon	Feb. 22-24	2.90	1.17	19,000
Elevation 2350 ft. South slope 61% Soil - sandy loam	Oct. 16-18	2.50	0.54	6,000
	Nov. 15-19	1.94	0.30	300
	Dec. 11-14	4.06	0.69	2,000
Pickens Canyon	Feb. 22-24	3.55	0.52	1,000
Elevation 4100 ft. SW slope 63% Soil - stony loam	Oct. 16-18	4.36	0.62	18,000
	Nov. 15-19	3.45	0.30	1,200
	Dec. 11-14	5.63	0.69	1,400

Note: In December 1933 heavy rains on the fresh burn caused an estimated erosion rate of 50,000 cubic yards per square mile, calculated from surveys of material deposited in debris basins and upon the valley floor below the burn.

Erosion Quantities from Extensive Plots in Burned Area.

These studies are carried out by means of permanent staked plots two milacres in projectional area which offer opportunity for observing soil losses from new burns. Several such plots, established at an elevation of 2800 feet on slopes of 25 and 60 per cent in the Cholo Point burn of July 1931 in the San Bernardino National Forest, were measured a few days after the burn and again following a heavy rainstorm in September. These plots were situated a short distance below a ridge top and thus represent something between the minimum and maximum rates of erosion, being inclined nearer to the minimum. From a single rain of approximately 2 inches, they suffered a loss of 6.6 cubic feet of soil per milacre, which is equivalent to 156,000 cubic yards per square mile. Assuming that one-third of the burned area was occupied by rock outcrops and ridge tops, and one-third by patches of broken rock and areas lightly burned, both presenting surface conditions on which erosion is practically negligible, the estimated rate of soil eroded from this burn still remains conservatively at more than 50,000 cubic yards per square mile. This erosion rate is identical with that determined by extensive surveys of the volumes of debris deposited in the Crescenta-Canada Valley below the Montrose burned area after the New Year's 1934 storm.

It should be emphasized that the data presented in the foregoing pages apply only to the specific areas under observation. The expression of rates of runoff and erosion on a square-mile basis is made merely to facilitate comparison. At the present stage of the studies it is not deemed justifiable to make broad extensions of rates obtained on small watersheds to very much larger areas, even though both may have similar topography and vegetational cover. So far as the work has gone, however, the results do indicate clearly that an undisturbed forest cover of the chaparral type functions powerfully to reduce both the runoff peaks and the rates of erosion.

Plot and Lysimeter Studies

In addition to the above described work in southern California, the California Forest and Range Experiment Station is conducting closely allied experiments at North Fork and at Berkeley which include determination of the effect of forest litter upon runoff, erosion, percolation and evaporation. These experiments are carried on under natural climatic conditions at North Fork, and under controlled conditions of precipitation and soil type at Berkeley. The following tables present typical results of these projects:

Table 4

PLOT EXPERIMENTS AT NORTH FORK, MADERA COUNTY, CALIFORNIA

Purpose: To determine the influence of natural vegetation upon runoff and erosion from plots one-fortieth acre in size.

Installation: Six plots, established in 1929 and 1930, each having horizontal dimensions of 10 x 108.9 feet, area 1/40 acre, average slope 32%, exposure southwest, elevation 2600 feet. The vegetation is a transition between brush woodland and ponderosa pine. The soil is a fine, sandy clay-loam (Holland-Sierra) derived from weathered granite.

Treatment: Two plots maintained with an undisturbed vegetative cover; two plots burned over once, 1930, and allowed to re-grow; two plots burned over repeatedly, 1929-31-32-33-34.

All Storms - Season of 1933-34

Storm no.	Storm date 1933-34	Precipitation in inches	Runoff in cu. ft. per acre			
			Undisturbed vegetative cover	Burned once (1930)	Burned annually (5 years)	
1	10-30-33	1.59	0	24	6	)
2	11-28	.03	0	0	0	) (1)
3	12-3	.72	0	12	8	)
4	12-11	6.35	14	130	668	
5	12-29	.18	0	0	0	
6	12-31	3.02	4	64	1854	
7	1-3-34	.03	0	0	2	
8	1-19	.38	0	0	0	
9	2-5	.17	0	0	0	
10	2-8	.24	0	0	0	
11	2-14	1.02	0	8	84	
12	2-18	1.23	0	12	146	
13	2-22	1.58	2	18	364	
14	2-26	1.15	0	12	226	
15	3-23	.29	0	0	0	
16	4-22	.05	0	0	0	
17	5-1	.14	0	0	0	
18	5-25	.61	2	2	14	
19	5-29	.51	0	14	28	
20	6-5	.24	0	0	0	
21	6-8	.14	0	0	0	
Totals		19.67	22	296	3400	
Runoff ratio			1	13	154	
Erosion (cu.ft./A)			trace	.4	85.8	
Erosion ratio			0	1	216	

(1) Low runoff rates from early storms on repeatedly burned plots result chiefly from greater rodent activity on these plots than on the others. The increase in rodents is ascribable to the temporary increase in amount of weeds and grass after fire.

The influence of vegetation is apparent in Table 4 from the ratios for the seasonal totals of runoff and erosion. That vegetation is the controlling factor is emphasized by the relatively small runoff and erosion from the once-burned plots upon which vegetation has been permitted to recover since 1930. On these plots a good growth of shrubs and herbs of the original pre-burn species is present, and this has begun to restore, through shading and litter accumulation, the receptivity of the soil to water. These plots are therefore gradually approaching the condition of normal control exhibited by the wholly undisturbed plots.

On the annually burned plots repeated denudation has resulted in heavy loss of permeable humus-bearing surface soil, with consequent exposure of soil of lower organic content to the sealing and eroding action of rain. This soil degradation has caused proportionate deterioration in vegetation: shrubs which sprouted vigorously after the first two burns made less growth after the later burns; the dense herb and grass cover following the early burns gave way gradually to a larger proportion of tarweeds and other "weed" species which are less effective as soil binders than the earlier species.

The inversion in runoff rates from storms 1 and 3, which yielded greater runoff from the once burned plots than from the frequently burned plots, is not uncommon. It is caused chiefly by the presence of a greater number of rodent burrowings on the frequently burned plot which make this plot more absorbent of the earlier rains than the less disturbed once burned plots. A second possible cause is the greater dryness of the annually burned plots after each summer's exposure to sun and wind, the vegetation on these plots offering less protection than the gradually increasing vegetation on the once burned plots.

Two other points of interest may be observed in Table 4:

(a) Approximately one-half inch of rain is required for an effective storm, i.e. one which produces runoff from the burned plots. The slight runoff indicated from the annually burned plots in the very light storm of January 3 resulted from delayed drip into the tipping bucket after the heavy storm of December 31.

(b) Once the rainy season is well begun and the ground of all plots thoroughly wetted, as by the storm of December 11, the runoff ratios for subsequent storms assume a relationship to cover conditions in line with that consistently obtained from similar plots elsewhere in California during the past seven years.

The runoff plots as employed to date are not adapted to the measurement of seepage. An experiment designed to determine the influence of forest litter upon seepage through the upper soil layers by means of soil tanks was installed adjacent to the runoff plots at North Fork, Madera County, California. In the initial series a 2-inch depth of litter from the nearby ponderosa pine forest was employed on the surface of the tanks in contrast to two tanks with bare soil surfaces. The results of this experiment are presented in Table 5. In Table 6 are presented results of a similar experiment at Berkeley, employing larger tanks and different soil types.

Table 5

SLOPE RAIN RETENTION TANKS AT NORTH FORK, CALIFORNIA

Purpose: To measure the influence of forest litter upon runoff, erosion, percolation and evaporation

Installation: Four rectangular tanks installed in 1932 with horizontal dimensions 20 x 50 inches, soil depth 21 inches, slope 27½ per cent. The top of the tanks are set flush with the ground and rain splitting edges protrude above. Other equipment includes baffle troughs, silt traps, and runoff and seepage collector tanks.

Treatment: Pans 12 and 14 are covered with a ponderosa pine litter 2 inches deep; and pans 13 and 15 are maintained with bare soil surfaces. The tanks are operated under natural conditions of climate and readings are taken daily during the period of activity.

RESULTS - RAIN SEASON 1933-1934

Total rainfall 19.64 inches

Pan area 1000 sq. in.	Soil depth 21 inches		Slope 27½%	
	Litter depth, 2 inches		Bare soil surface	
Pan numbers	12	14	13	15
Runoff (as % of rain)	1.3	1.5	26.3	22.5
Seepage (as % of rain)	56.9	53.4	18.2	20.9
Evaporation and retention (as % of rain)	41.8	45.0	55.5	56.6
Eroded material in cu. in.	0	0	43.6	40.9

Table 6

SOIL-TANK STUDIES AT BERKELEY, CALIFORNIA

Purpose: To measure the influence of forest litter on runoff, percolation and erosion for different soil types.

Installation: 8 rectangular tanks, horizontal dimensions 2 x 5 feet, soil depth 30 inches, slope 28 per cent. The tanks are set above ground and equipped with baffle troughs, silt traps, seepage and runoff collector tanks, and 9 slope rain gages placed between the tanks.

RESULTS - RAIN SEASON 1933-1934

Total rainfall 14.13 inches

Result recorded	Aiken sandy-loam		Holland-Sierra sandy-loam		Altamont clay-loam			
	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8
	Bare soil	2"P.P. litter	Bare soil	2"P.P. litter	Bare soil	2" Oak litter	2"P.P. litter	2"P.P. litter
Runoff as % of rain	10.49	2.83	38.07	2.21	9.74	0.51	3.38	2.32
Seepage as % of rain	18.93	54.11	6.40	78.03	48.24	56.92	73.50	55.22
Evaporation and retention as % of rain	70.58	43.07	55.53	19.66	42.02	42.57	23.12	42.46
Eroded material:								
Dry wt. in lbs.	0.85	0	2.51	0	0.71	0	0	0
Vol. in cu. in.	28.24	0	83.47	0	23.47	0	0	0

Note: Top soil on tank #5 contains considerable organic matter.
P.P. represents ponderosa pine litter.

Conclusion

The quantitative results of experiments of the type here described must inevitably exhibit wide variation owing to the variable factors of rainfall, topography, soil, litter and vegetation, to name only the most obvious. Forestry deals with a vast physical and biological complex which does not always lend itself to satisfactory sampling or to precise measurement. This is especially true with regard to the relations between vegetation, soil and water. By reason of that very complexity the effort to determine quantitatively the influence of the forest upon the water cycle must be executed on a large scale and over a considerable period of time. It is probable that the net results will be most usefully expressed as broad averages and trends rather than as definite quantities. The function of small-scale intensive studies is, like those of the laboratory, to isolate factors, to determine their relative weight in bringing about the net result, and thus possibly to discover points at which manipulation may be exercised to modify the net result to human advantage.

The foregoing tables present typical results of experiments in the field of forest influences on both a large and a small scale. Despite quantitative variations, the results consistently indicate that vegetation and its natural concomitant, litter, function powerfully to reduce the runoff rates of rainfall from sloping lands, to reduce the volumes of erosion, and to induce the percolation of water into the soil.

Previous Publications

1929. Further Studies of Factors Affecting Surficial Runoff and Erosion, by W. C. Lowdermilk, Proceedings Internat. Cong. Forestry Experimental Stations, Stockholm, 1929.

1930. Influence of Forest Litter on Runoff, Percolation and Erosion, by W. C. Lowdermilk, Journal of Forestry, Vol. 28, pp. 474-491.

1933. Studies in the Role of Forest Vegetation in Erosion Control and Water Conservation, by W. C. Lowdermilk, Proceedings Fifth Pacific Science Congress, June 1933. (Pub. 1934, by University of Toronto Press.)

1934. Still Further Studies on Absorption of Rainfall in its Relations to Surficial Runoff and Erosion, by W. C. Lowdermilk and P. B. Rowe, Transactions of the American Geophysical Union, Fifteenth Annual Meeting, 1934.

PROTECTION OF VEGETATIVE COVER FROM FIRE

It is safe to say that the entire portion of the drainage areas of the Los Angeles, San Gabriel, and Rio Honda Rivers, that are composed of watersheds other than the flat lands which are under cultivation and improved, are provided with fire protection. The protection provided varies in intensity with relation to the importance from the standpoint of improvements as well as the location of the high risks and hazards, and high-occurrence zones.

The map that accompanies this report will give a graphic picture of the three principal types of cover that prevail upon the watershed proportion of these drainage basins; and will also indicate the proportion of the drainage basins that lie within the Angeles National Forest, and the proportion that lies outside which is provided protection by the Los Angeles County Forestry Department. The total area within the National Forest is approximately 345,000 acres -- 58,000 acres of this being timber, and 287,000 acres being mixed chaparral. Outside the National Forest, there are approximately 65,000 acres of watershed, upon which the cover is principally chaparral and grass, affecting these three drainage basins. The balance of the drainage areas of these three rivers is composed of the valley floors, developed for agricultural, industrial, or residential purposes.

The methods used by the Forest Service in the protection of this area have changed considerably in the last decade; and the degree of intensity of protection provided has been gauged largely by the amount of money available annually for protection improvements as well as for the

hiring of personnel for the operation of protection forces.

By studies, we have determined where our high-occurrence zones are located upon the National Forest; and, naturally, have intensified the protection in these areas with the objective of controlling fires at the start. In the past we have considered if we could hold the average annual burn to one-half of one per cent of the entire area each year, that we were providing adequate protection. Due to the high inflammability of the chaparral cover, and rapidity of spread under adverse weather conditions, in order to even hold down to one-half of one per cent annually, we found it necessary to so organize our suppression forces to assure control of fires during the first period--meaning the first running period from the time they start. Fires ordinarily have a running period varying from two to ten hours, and sometimes longer, out of each twenty-four hour period.

Plans for this type of protection involve the construction of truck trails to make the country accessible, telephone lines for communication, careful visibility studies for the placement of lookouts, construction of firebreaks on strategically located ridges, and the setting up of a trained organization to function when fire starts. This includes a central dispatching system, operated through our Pasadena branch office; and direct communication facilities to each District Ranger and to each suppression crew on the Forest. Our purpose of course, is to reduce to a minimum the time elapsed between first discovery and the first action on any given fire.

You perhaps have noticed in travelling over the Forest that in

many of our canyons on the front there are many special-use tracts given over to recreational use and having quite a large investment in summer homes and cabins. In our fire protection plans, it is necessary for us to take into consideration the additional risk of these uses and the values at stake; and the distribution of our tank truck equipment, patrolmen, and fire suppression crews is based upon the high-occurrence zones first, and second upon the values at stake. Again our purpose being to reduce to a minimum the elapsed time in those areas where we can expect fires to happen, and in those areas where serious damage can occur in a very short time.

The following is a tabulation of the burned area within the three drainage areas of the Los Angeles, Rio Honda, and San Gabriel Rivers, from 1919 to 1935, as well as the total number of fires that have occurred on the Angeles Forest during that same period by years:

Year	Los Angeles Acres	Rio Honda Acres	San Gabriel Acres	Total Acreage	Number of Fires
1919	60,000		50,640	110,640	34
1920					40
1921					36
1922	1,600			1,600	43
1923					6
1924	850		48,500	49,350	32
1925	6,720			6,720	27
1926	3		1	4	16
1927	12		2	14	20
1928	374	78	34	486	20
1929	71	4	89	164	43
1930	43	2	5	50	28
1931	9		20	29	43
1932	432			432	38
1933	4,830		3	4,833	51
1934	3,550		3	3,553	31
1935	3,269	98		3,367	51
	81,763	182	99,297	181,242	559

The history before 1919 does not indicate that we had many more starts than we have had since, but generally indicates a much larger area per fire on the average than we have had especially since 1924.

From 1924 to 1933, you will see that the average area burned was very small due to a series of very favorable years. In the last three years, 1933, 1934 and 1935, the area burned jumped up in spite of the fact that we had a much more intensified protection system than we had previous to 1933. This was due in a large way to adverse weather and wind conditions which prevailed when fires occurred.

Since 1933 we have been fortunate in having a number of CCC camps on the Forest that aided us materially in getting action on fires; and I am quite certain that had we not been supplied with this trained labor, our burned areas for the last three years would have been much more serious than the tabulation shows.

The cost per acre for protection before the CCC program came into the picture varied annually depending, of course, principally on the amount of money made available for protection; first, for investment in protective improvements; second, for salaries and wages of the fire protection organization. In the period from 1920 to 1925, our total expenditures annually, including investments, probably did not exceed fifteen to eighteen cents an acre. However, since the CCC came into the picture, we have been able to speed up our protection program materially and have built a great many miles of roads, firebreaks, telephone lines; and have a building construction program nearing completion which includes lookouts and guard stations as well as fire suppression crew barracks. We have

worked out comprehensive plans showing our needs in addition to the above to insure a proper transportation and communication system on the Forest as well as a complete detection and housing system for the personnel. Also, we have estimates on the needed additional equipment. This is itemized as follows:

Construction of 600 miles truck trails	$1,800,000
92 miles telephone line	27,800
250 miles firebreaks	250,000
40 buildings, involving barracks, guard stations, and lookouts	80,000
125 water developments, including catch basins and storage tanks	150,000
35 tank trucks and other miscellaneous fire equipment	150,000
Total Investment Needed to Complete Plan within San Gabriel and Los Angeles River Area	$2,457,800

The firebreak item of 250 miles may be modified within the next few months since we are conducting an intensive study as to the relative value of firebreaks on major divides of watersheds as well as on lateral divides in smaller drainage areas. It is possible that this figure may be increased, or may be decreased when the study is completed.

If this entire amount of money was made available at one time, I am satisfied that the plant could be completed within two years. However, at our present rate of appropriation, including the use of an average of four or five CCC camps, we could not expect to complete it for many years since our total expenditures would probably amount to approximately $250,000 per year.

After the plan is completed, we are necessarily faced with the rather heavy maintenance cost especially on roads and firebreaks, but not a very heavy increase in cost of operation of plant in the nature of personnel. An estimate of what the annual maintenance cost of the improved plant is tabulated as follows:

Roads	$30,000
Telephone lines	600
Firebreaks	50,000
Other miscellaneous improvements including water systems and buildings	8,500
Salaries of protective force and personnel	10,000

Rounded off, this is approximately a cost of $100,000 a year. This can be converted into a cost per acre for the area necessary to protect within and bordering upon the drainage areas of these three principal rivers, amounting to approximately thirty cents per acre per year. This, as compared to the average annual expenditure for protection on National Forests, is very much out of line. However, the potential threat of damages running into the millions as the result of very small areas burned, as mentioned previously in this report about the Montrose Flood, indicates quite clearly the justification of this type of intensive protection in all the areas adjacent to the densely settled San Gabriel Valley notwithstanding the fact that there is practically no merchantable timber upon the area.

Debris Dams

The possibility of constructing debris dams in the channels of

certain smaller watersheds that are subject to high fire hazard, along the San Gabriel mountain front has been given consideration by the Forest Service. An investigation of the small drainage areas along the forest boundary from San Fernando to San Antonio Canyon was made by Mr. Niel F. Meadowcroft, under the direction of Mr. E. W. Kramer, Regional Engineer. A copy of Mr. Meadowcroft's report entitled "Debris Dam Survey of the South Slope of San Gabriel Mountains" is attached for your files.

COPY

O-E
Improvement
Angeles

May 1, 1936

Mr. Theodore Wyman
U. S. Engineers' Office
751 South Figueroa Street
Los Angeles, California

Dear Mr. Wyman:

Reference is made to Mr. Show's letter of April 3 addressed to you, also to the statements presented by Mr. E. W. Kramer, Regional Engineer, at the meeting in Patriotic Hall on March 31, 1936. Subsequent to that, your representative, Mr. Mosher, called at our office leaving with us an outline of facts that you desired covering the California Forest Experiment Station activities and Fire Protection.

I am, therefore, enclosing herewith a statement which I believe covers the points that you are interested in as to the influence of vegetative cover within the National Forest upon the flood control program of the Los Angeles and San Gabriel Rivers. We have gathered this information together rather hurriedly, and it reflects data prepared by representatives of the California Forest Experiment Station as well as that gathered by the staff of the Angeles Forest here in our office.

If there are any other features regarding the protection in the Angeles Forest and the influence of vegetative cover on the run-off of these two drainage areas that we can furnish you, do not hesitate to call upon us.

We feel that it would be very desirable for you and one or two members of your staff to arrange at some early date to carry out the tentative plan of visiting the Experiment Station plots at San Dimas Canyon. I hope that we will hear from you soon as to when it will be convenient for you to look over these plots.

Very truly yours,

Wm. V. Mendenhall
Forest Supervisor

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FORESTATION - FIRE PROTECTION

1. What portion of the drainage areas of the Los Angeles, San Gabriel, Rio Hondo are protected from forest fires?
   a) Location
   b) Percent of area
   c) How protected

2. What measures are now taken following the denudation of an area by fire by the Forest Service?

3. San Dimas Experimental Station
   1. Object?
   2. Tangible results?
   3. Experiments - progress or anticipated

4. Fire Protection
   a) Estimated cost, unit area
   b) Length of time required to provide per unit area
   c) Maintenance
      1. Nature
      2. Cost

5. Necessity for vegetative covering for fire protection

FORESTATION

1. Portion of drainage areas now forested

   1. Area
   2. Type vegetation

Note: (attached to above outline)

J. D. SINCLAIR 5/7/36

This is the outline that Mr. Mosher of the Army Engineers made out rather hurriedly when he called at our office for the information and report.

W.V.M.

U.S. Forest Service
Pacific Southwest Region
Publications and Information Center
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Vallejo, California 94592-1110